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Overview of the U.S. EPA (Environmental Protection Agency) Electrostatic Particulate Research and Development Program

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Research Triangle Park, NC

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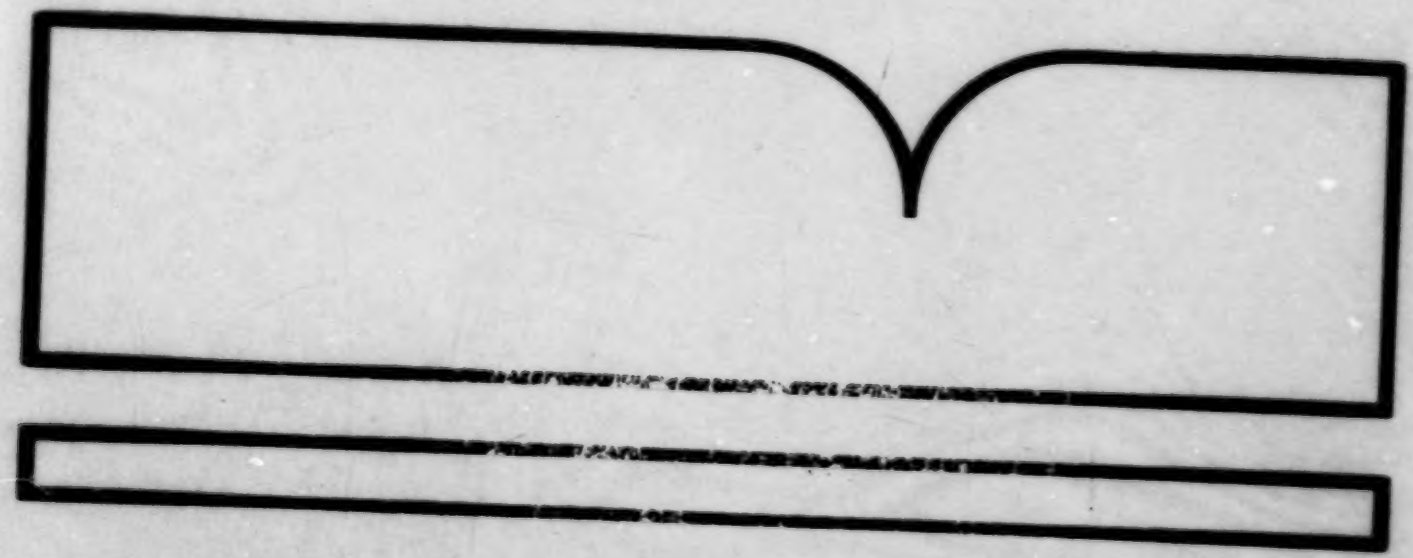

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OVERVIEW OF THE U.S. EPA ELECTROSTATIC PARTICULATE R&D PROGRAM

by

Normak Plaks
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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16. ABSTRACT The U.S. EPA's particulate research and development program, divided between an in-house laboratory effort and extramural work at various research institutes, makes use of electrostatics in most of the work associated with stack or ducted emissions. Research facilities which offer a large degree of flexibility and capability are described. Significant work currently underway, making use of electrostatics, includes: (1) smooth large-diameter discharge electrodes (9-10 mm), that have been evaluated in 1/3- and 10-MW pilot units; (2) the multistage electrostatic precipitator (ESP), consisting of several two-stage ESPs in series, each using cold-pipe prechargers and collectors with large diameter electrodes: (3) the E-SOX process, combining the multistage ESP with a spray dryer in an existing ESP, for simultaneous SO2 and fly ash removal (including injections of soda ash and lime slurry droplets); and (4) electrostatically augmented fabric filtration with fly ash (including spray drying by-product material).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Dust	Pollution Control	13B	11G
Flue Gases	Spray Drying	Stationary Sources	21B	07A, 13H
Electrostatics	Sulfur Dioxide	Particulate	20C	07B
Particles	Fly Ash	E-SOX Process	14G	
Electrostatic Precipitators	Sodium Carbonates	Fabric Filters	13I	11E
	Fabrics			

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OVERVIEW OF THE U.S. EPA ELECTROSTATIC PARTICULATE R&D PROGRAM

Norman Plaks
Chief, Particulate Technology Branch
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, N. C. 27711

ABSTRACT

The U.S. EPA Particulate R&D Program, which is divided between an in-house laboratory effort and extramural work done at various research institutes, makes use of electrostatics in the majority of the work associated with stack or ducted emissions. Research facilities which offer a large degree of flexibility and capability are described. The in-house facilities are generally operated by EPA personnel; from time to time visiting scientists and engineers in particulate control work there.

Significant work that is currently underway which makes use of electrostatics is as follows:

- The use of smooth large-diameter discharge electrodes (9-10 mm), which have been evaluated in 1/3- and 10-MW pilot units, shows that, with a high resistivity dust (2×10^{12} ohm cm), an emission reduction and improvement by a factor of four can be achieved when compared to 3 mm electrodes.

- The multi-stage electrostatic precipitator (ESP), consisting of several two-stage ESPs in series, each using cold-pipe prechargers and collectors with large diameter electrodes, indicates that an efficiency greater than 99.6% for a fly ash having a resistivity of 2×10^{12} ohm cm is achievable with an SCA of less than 50 m^2 per actual m^3/sec.

- In the E-SOX process the multi-stage ESP has been combined with a spray dryer in an existing ESP, for simultaneous removal of sulfur dioxide (SO_2) and fly ash. With injections of soda ash and lime slurry droplets, SO_2 captures of 90% and 60%, respectively, were achieved. Preliminary cost analysis shows that the E-SOX process is very competitive with other desulfurization processes.

- In electrostatically augmented fabric filtration, with fly ash, pressure drop reductions by a factor of two have been achieved over that of conventional filtration . With spray drying by-product material, a pressure drop reduction by a factor of more than five has been seen. With fly ash, when operating at the lower temperatures and higher moisture conditions of spray drying, pressure drop reductions by a factor of four have been seen.

INTRODUCTION

The United States Environmental Protection Agency Particulate R&D Program is part of an overall research effort to support the environmental goals of the Agency.

The particulate matter R&D program is divided between an in-house laboratory effort and extramural work done at various research organizations and which, in general, complements the in-house work. Particulate R&D is performed for control of stack or ducted emissions and fugitive or non-ducted emissions, reducing operation, maintenance, and control of condensation aerosols. The majority of the work associated with stack or ducted emissions makes uses of electrostatics and includes both electrostatic precipitators and electrostatically augmented fabric filtration.

This paper describes the EPA in-house research facilities and several key project areas currently being worked upon for the control of particulate matter by the use of electrostatics.

The EPA in-house experimental facility, located at Research Triangle Park, North Carolina, includes pilot ESPs, baghouses, and a laboratory resistivity measurement system. A unique piece of equipment is the optical ESP shown in Figure 1. This device, having sides of acrylic plastic, allows observation of corona to be made concurrent with electrical measurements. This ability has proven to be extremely useful. In addition to the in-house equipment the program has larger pilot ESP and fabric filtration equipment at several field locations. The major equipment is more fully described in the Appendix.

ELECTROSTATIC PRECIPITATORS

EPA's electrostatic precipitator research

has concentrated on improving performance and operation especially with high resistivity dusts and back corona, decreasing size and cost, upgrading of performance for operation with desulfurization systems, integrating sulfur dioxide control into the ESP, and developing performance and cost models.

Historically, with low resistivity dusts, ESPs have been designed for high corona currents. Even with these high corona currents the absence of a back corona problem allows development of high field strength. As a consequence the ESPs operated well and the particles were easily charged and collected. High corona currents were achieved by use of small diameter discharge wires (approximately 0.3 cm) or use of electrodes with a multiplicity of discrete discharge points. In cases where the allowable useful current is limited by high resistivity the low corona onset voltage and fairly steep voltage/current relationship results in a decreased electric field strength. The combination of low current density and electric field produced by conventional discharge electrodes requires that a high SCA be provided to meet emission standards.

Experimental studies at the 840 actual m^3/min field pilot unit at TVA's Bull Run power plant and the in-house 28 actual m^3/min pilot ESP have shown that the use of larger diameter, smooth-surface electrodes (approximately 1 cm in diameter) can provide a significant improvement in ESP performance--especially when high resistivity dust is collected. The large diameter electrodes allow operation at high field strengths and useful current densities. The operating current density, and thus the useful operating power, for the large diameter electrodes was found to be less than that for conventional size electrodes. For moderate (8×10^{10} ohm-cm) to high ($> 2 \times 10^{12}$ ohm-cm) resistivity dusts, the increase in the electric field more than compensates for the reduction in useful power. As can be seen from Table 1, the large diameter wires reduce the penetration for high resistivity dust by a factor of 4 and the penetration for moderate resistivity dust by a factor of 1.18. Economic analysis has shown that the large diameter wire technology is applicable in both new and retrofit situations when the dust resistivity is greater than about 8×10^{10} ohm-cm. The application of this technology is being further pursued.

In conventional ESPs particle charging and collection take place in the same electrical section. It has been found that, for the higher resistivity dusts, separation and optimization of the charging and collection steps can lead to significant improvements in performance.

A number of precharger techniques have been worked upon including the trielectrode [1], cold-pipe [2], and charged droplet. One of the most promising is the cold-pipe precharger shown in Figure 2. It consists of discharge wires interspersed with grounded pipes through which cooling water flows. The purpose of the cooling water is not to cool the gas stream but to cool the dust layer that forms on the pipes. Cooling the dust layer decreases the resistivity, thereby allowing high field strength and current which puts high charge levels on the particles.

Combining the cold-pipe precharger with wire-plate collectors using large diameter wires provides an even further improvement in performance. Large diameter wires in the collector sections allow development of high field strengths and also provide sufficient corona current to clamp the dust layer to the plates, thereby minimizing non-rapping reentrainment. Figure 3 shows the multi-stage ESP which consists of collector sections each of which is preceded by a cold-pipe precharger. With high resistivity particulate matter a multi-stage ESP will give the same collection efficiency as a conventional ESP operating with relatively low currents and fields and having four or five times the collecting plate area. Operation of the multi-stage ESP with the cold-pipe precharger and large diameter wires in the collector sections has been done on the EPA in-house 28 actual m^3/min ESP. Further work on this concept is scheduled on the 425 actual m^3/min ESP at Valmont.

Multi-staging, when retrofitted to an ESP that is working well and is in compliance with the particulate matter regulations, will have more capacity than is actually needed. This suggests that some portion of the ESP internals can be removed. This freed up space, fitted with suitable nozzles, can be used for removal of sulfur dioxide from a flue gas by injecting droplets of an alkaline reagent.

This system, which has been named E-SOX, for the removal of sulfur dioxide along with the particulate matter in an ESP, is shown schematically in Figure 4. The ESP has had some internals at the inlet removed; cold pipe prechargers and large diameter wires are installed in the remainder of the ESP. The alkali reagent shown being used here is a high calcium lime that has been slaked and slurried by techniques that have been developed for conventional spray drying flue gas desulfurization.

The E-SOX system has been evaluated on the in-house 28 actual m^3/min ESP using two fluid nozzles for the alkali reagent injections. The sulfur dioxide removal results are shown in Figure 5. Two reagents were used, sodium carbonate solution and lime slurry. With the sodium carbonate in concentrations of 15 and 30% by weight and at flow rates ranging from 26 to 75 liters per hour, the sulfur dioxide removal ranged, for an inlet concentration of 1200 to

1500 ppm, from about 50% to almost 90%, within 2 seconds of residence time. With a slurried lime injection, whose concentration was 7 and 15% by weight, the sulfur dioxide removal in the same 2 seconds of residence time ranged from about 40% to almost 60%. Maximum sulfur dioxide was removed at the higher injection rates. The removal was not found to be highly sensitive to reagent concentration. For the lime experiments the maximum stoichiometry of calcium to sulfur was about 1.8 based upon inlet sulfur dioxide. In both cases the injected droplets were completely dried in considerably less than 2 seconds and the deposits on the ESP could be rapped off. In this series of experiments no attempt was made to optimize the sulfur dioxide removal. In a typical ESP retrofit enough of the internals should be removable to obtain 2 seconds of residence time. The remainder of the ESP can be multistaged to not only regain original particulate collection performance but to also capture the injected reagent.

The costs for E-SOX have not been fully worked out. However, it is expected that the process should be among the lowest cost of the various flue gas desulfurization techniques. The use of an existing ESP makes it unnecessary to add additional equipment, such as a spray drying chamber, for sulfur dioxide capture; the lime system is the same as is required for some of the other processes. One advantage of E-SOX is that the injection of a large quantity of droplets lowers the gas temperature and volume which causes a reduction in particle resistivity and an increase in SCA. The E-SOX project is expected to be moved onto a larger pilot unit using actual flue gas as the next stage in its development.

E-SOX, if successfully developed, would be a low-cost retrofit for reducing emissions of sulfur dioxide from coal-fired power plants. This is significant for several reasons: (1) coal-fired power plants with ESP particulate control technology represent the largest source category for sulfur dioxide emissions in the U.S., and (2) the high cost of controlling sulfur dioxide with existing technology is a major issue to be considered in air pollution policy analysis. It would be especially useful for those situations in which there is no room for a spray drying chamber.

FABRIC FILTRATION

Historically, fabric filtration has been used for a considerable time in industry. More recently with increasing use of low sulfur coals, with their high resistivity fly ashes, it is being applied more frequently to utility and industrial boiler particulate matter control.

In the EPA Particulate Program it has been concluded that, of all the parameters involved in fabric filtration design, electrostatics, when properly applied, is the dominant.

Electrostatically augmented fabric filtration (ESFF) is a technique in which an electrostatic field is established across the fabric to cause preferential deposition of the particulate matter on some areas while leaving other areas open to gas flow. This open area causes a lowered pressure drop for the baghouse. Much of the work to date has been with the electric field parallel to the surface of the fabric. Typically the field was generated between electrodes, at the surface of the fabric, running the length of the bag, and placed about 2 cm apart. The electric field strength is from about 2 to 8 kV/cm. In pulse-jet operation the wire support cage is adapted for developing the electric field as shown in Figure 6 [3]. Adjacent wires are insulated from each other thereby allowing the cage itself to be electrified. For reverse air, which does not use a cage, stainless steel yarns have been woven into the fabric warp as shown in Figure 7. The fabric is fiberglass with a Teflon finish; the yarn is 316L stainless steel having 90 fibers each 22 m in diameter [4]. The alternate yarns have the electric field developed between them, the same as in pulse-jet.

The ESFF effect has been shown for fly ashes on the small in-house baghouses. It has been shown for both reverse-air and pulse-jet with the 28 actual m^3/min pilot unit having 2.4 meter bags on an industrial boiler at the DuPont Waynesboro facilities. It has been operating for about 14 months, using reverse-air, in a 140 actual m^3/min pilot unit at the Southwest Public Service Harrington power station in Amarillo. At the Harrington power plant the bags were full utility size, each being 9.2 meters long and 0.3 meter in diameter as shown in Figure 7.

Typically, for fly ash the pressure drop across an ESFF baghouse is about 50% of the pressure drop across a conventional baghouse. [3,5] This means that one can minimize the pressure drop and consequently the fan power or else decrease the number of bags and consequently the capital cost.

A series of experiments were performed in-house on both reverse-air and pulse-jet using redispersed particulate matter from a spray drying process used in sulfur dioxide capture. In spray drying a lime slurry is injected into a chamber to react with the sulfur dioxide. The resulting mixture consists of fly ash, and reacted and unreacted lime. For spray drying by-product particulate matter, the pressure drop was reduced by about a factor of six as compared to conventional filtration. Figure 8 is a pressure vs time trace which shows dramatically the effects of turning the field on. At the start, with the power off, the pressure drop was continuing to rise and would have eventually gone off the chart if continued. The

pressure drop started to respond immediately to turning on the field.

The ESFF effect that has been discussed up to now has been based upon the action of an electric field upon particulate matter containing only natural charge. No corona for charging the particles was generated. The measured natural charge on fly ash was about 0.1 to 0.2 C/g, for spray drying byproduct the charge to mass was 1 to 2 C/g. The difference in the pressure drop reduction for fly ash as compared to spray drying material shows the effect of this difference. Varying the electric field has also been seen to affect the pressure drop reduction.

Work is underway on techniques in ESFF for simultaneously increasing the field strength and increasing the charge on the particles. There is good indication that by doing this it would be possible to achieve pressure drop reductions for most particulate matter that will equal that which was achieved with spray drying material.

OTHER ACTIVITIES

In addition to the work described in previous sections, EPA has a strong program in modeling and fundamentals. The purpose of the modeling/fundamentals program is to provide design and performance models for the particulate control devices, which are based on a sound understanding of the underlying physics of the particulate collection process. The ESP work has resulted in a computer model that is in wide spread use by vendors, users, and researchers [6]. Work is underway to improve the ESP model in the areas of effects of electrode geometry, electrical conditions, and space charge. The program has produced a useful model for fabric filters. The current version of the model does not include electrostatic effects. However, work is underway to introduce the effects of application of electrostatics into the fabric filtration models.

From time to time eminent workers in the field of electrostatics and pollution control visit and work at the EPA in-house laboratory facilities. Included among these are J. Dalman, P. Lawless, S. Masuda, R. McLean, D. Pontius, and G. Rinard. The research conducted under these cooperative programs ranged from evaluation of flat plate discharge electrode to careful studies of corona from dirty wires.

CONCLUSION

This paper has presented an overview of the EPA electrostatic precipitator program. Key areas have been discussed. Work will be continuing on large diameter discharge electrodes, multi-stage ESPs, E-SOX, and ESFF. In conjunction with these areas a strong fundamentals and modeling effort will be continued. Cooperative work at the in-house facilities by workers in electrostatics will be encouraged and continued.

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[6] Faulkner, M.G. and J. L. DuBard: "A Mathematical Model of Electrostatic Precipitation (Revision 3)" Vols. I and II, EPA-600/7-84-069a and b (NTIS PB 84-212 679 and 84-212 687), June 1984.

Table 1. COMPARISON OF LARGE AND SMALL DIAMETER DISCHARGE ELECTRODES

Resistivity ohm-cm	8×10^{10}	2×10^{12}
Electric field[a] ratio (E_L/E_S)	1.60	1.19
Current density ratio (j_L/j_S)	0.41	0.69
Power ratio (P_L/P_S)	0.55	0.81
Overall migration velocity ratio (w_L/w_S)	1.12	1.33
Penetration ratio (Pt_L/Pt_S)	0.80	0.25

[a] Subscript L refers to large diameter electrodes, and subscript S refers to small diameter electrodes.

APPENDIX - Major EPA R&D Particulate Control Pilot Equipment

ESP

1. Flow Rate 28 actual m^3/min
   Temperature Range ambient to 350°C
   Gas Velocities 3 to 6 m/sec
   Collection Plate Dimensions 1.2 x 1.2 m
   SCA (plate spacing 23 cm, velocity 1.5 m/s) 28 $m^2/m^3/sec$
   No. of Sections 4
   Power Supplies 1 section, 0-100kV positive or negative polarity with current rectified, filtered or unfiltered; 2 pulse power supplies
   Dust Feed Rates to 23 g/m^3
   Water Content of Gas 2 to 10% by volume
   Material of Construction stainless steel
   Plate Spacing 12.7 to 38.1 cm
   Discharge Electrodes can be varied
   Prechargers cold-pipe & trielectrode
   Location EPA, Research Triangle Park, NC

2. Temperature ambient
   Collection Plate Dimensions 1.2 x 1.2 m (2 per section)
   No. of Sections 2
   Power Supply positive and negative supply per section to 100kV
   Plate Spacing 15.2, 22.9, 30.4 cm
   Discharge Electrodes can be varied
   Material of Construction acrylic plastic & aluminum
   Location EPA, Research Triangle Park, NC

3. Flow Rate 420 actual m^3/min
   No. of Sections 4
   SCA at Design Flow Rates 50-60 $m^2/m^3/sec$
   Temperature controllable 138-149°C
   Type Unit large experimental unit
   Power Supplies one per section to 100kV
   Operation Time 24 hr/day
   Prechargers cold-pipe, trielectrode
   Discharge Electrodes can be varied
   Location Valmont Power Station Colorado Public Service Boulder, CO

4. Flow Rate 840 actual m^3/min
   No. of Sections 4
   SCA at Design 50-60 $m^2/m^3/sec$
   Temperature 138-149°C
   Type Unit small commercial
   Power Supplies one per section to 100 kV
   Prechargers trielectrode
   Discharge Electrodes can be varied
   Location Bull Run Power Station, TVA Oak Ridge, TN

FABRIC FILTRATION

1. Temperature ambient to 200°C
   Compartments 2
   Bags - Number 1 per compartment
   - Length 1.22 m maximum
   - Diameter 0.2 m maximum
   Cleaning reverse-air and pulse-jet
   Flow Rate 0.28 to 1.68 m/min
   Operation ESFF or conventional filtration
   Location EPA, Research Triangle Park, NC

1. Temperature 200°C
   Compartments 2
   Bags - Number 6 per compartment
   - Length 9.2 m
   - Diameter 0.3 m
   Cleaning reverse-air or shake-deflate
   Flow Rate 142 m^3/min
   Power Supplies for ESFF
   Number 2
   Rating 15kV @10 mA (each power supply connected to 3 bags)
   Location Harrington Power Station Southwest Public Service Amarillo, TX

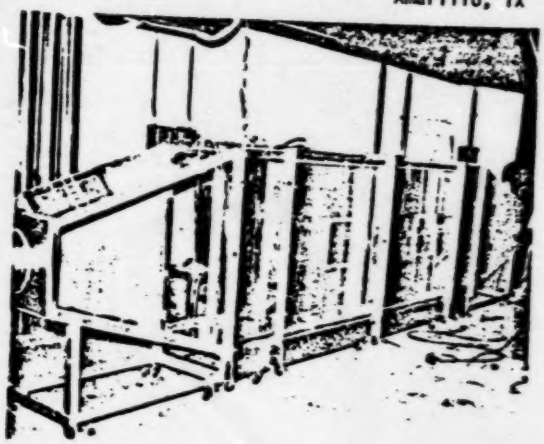

Figure 1. Optical ESP Constructed of Acrylic Plastic and Aluminum

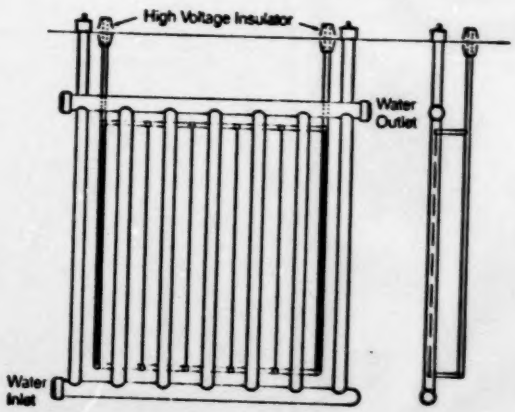

Figure 2. Cold- Pipe Precharger

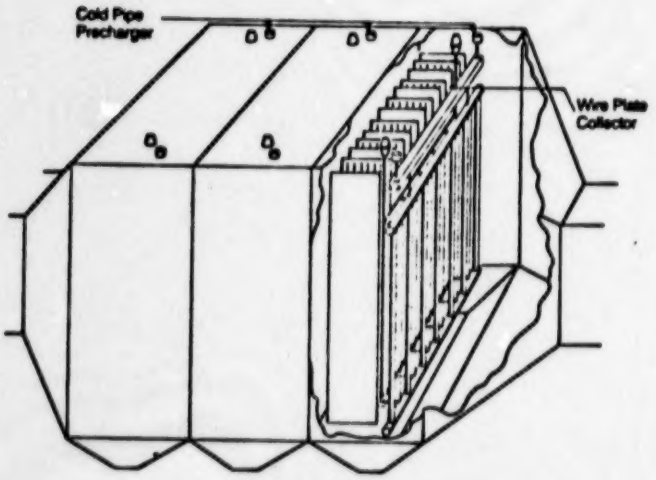

Figure 3. Multi-Stage Electrostatic Precipitator

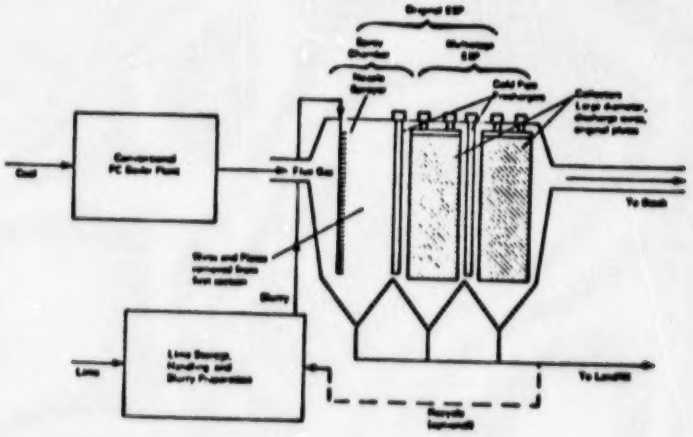

Figure 4. Schematic of E-SOX Process

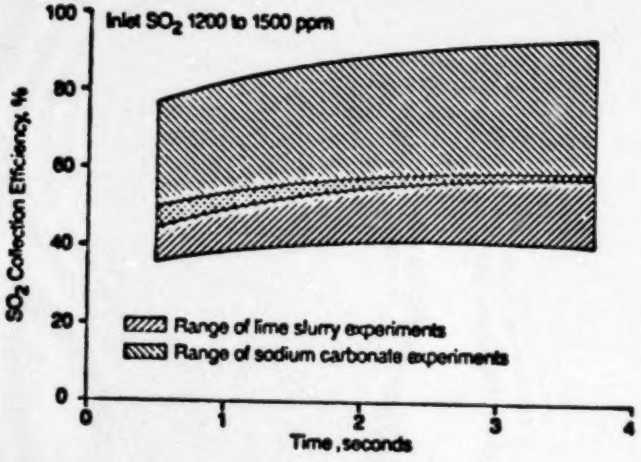

Figure 5. E-SOX Data for Sodium Carbonate and Lime Slurry Experiments

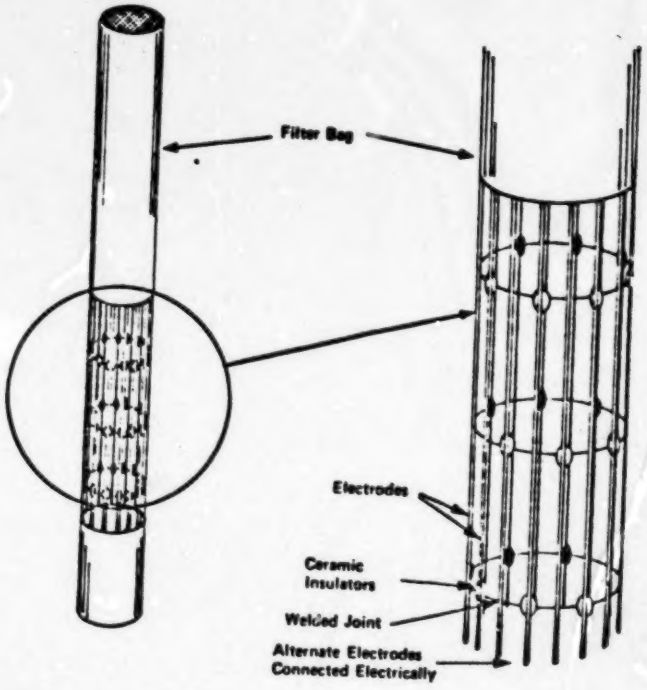

Figure 6. Pulse-jet ESFF Electrode/Bag Assembly

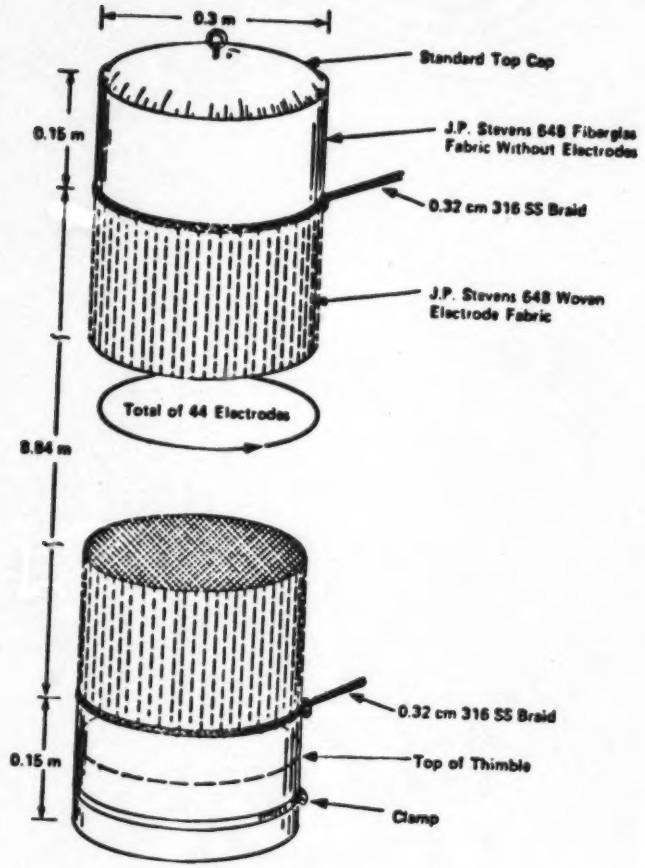

Figure 7. Reverse Air Woven-in Electrode ESFF Bags

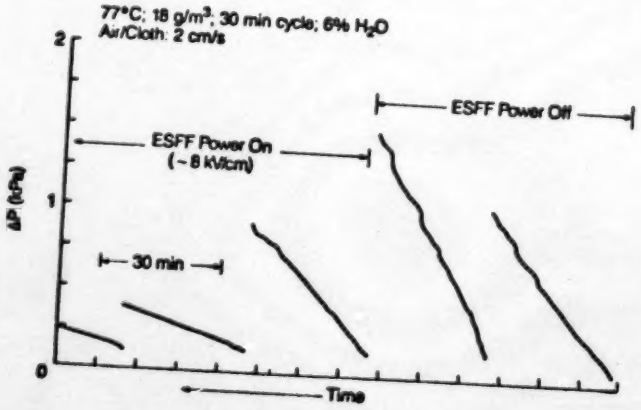

Figure 8. Effect of Turning ESFF Field On